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Master's degree in Applications
and Technologies for
Unmanned Aircraft Systems

MASTER THESIS

TITLE: Payload bay design and manufacturing for a fixed wing UAV with VTOL capability

DEGREE: Master's degree in Applications and Technologies for Unmanned Aircraft Systems (Drones)(MED)

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DATE: September 6, 2018

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Overview

The company Venturi is designing a drone for inspection, and it has to be able to carry some different payloads as a LiDAR, electro-optical and thermal sensors and a gas sensor to methane leakages. All these payloads need a mount to be held to the drone, so this thesis will explain how all these mounts were designed and the future steps to continue improving these fixations.
The drone will be sold, and the company will also operate with it.
My labour in the company consisted in to do market research and a study of the different payloads to be able to implement it in the drone.
In this thesis, there is a review of the market research but is more focused on all the mounts of the different payloads that will be used in the aerial inspections to be sure that these payloads will be well fixed.
There are also some other components that were designed and constructed for the drone.

This thesis is dedicated to
my teammates of Venturi
and all my family for
the support received.

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INTRODUCTION

During the last years, the drone market (also known as UAV, Unmanned Aerial Vehicles) has grown exponentially.
Drones are replacing previous aerial inspection methods, such as light airplanes, helicopters or satellites.
Its main advantages consist of reduced investment and operating costs, as well as human risks since there are no pilots or on-ground operators.
After talking to potential customers, it is known that the fixed cost of renting a helicopter is around 150.000 euros/month or 1.000 euro/hour for hiring services.
The figure 1 shows a comparison between de different costs depending on the inspection method used for each kilometre inspected.
The V01 that is shown in the figure is concerning to the drone that Venturi wanted to construct.

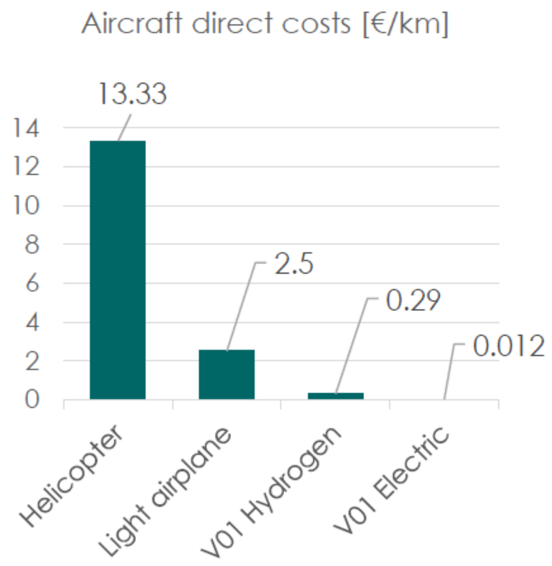


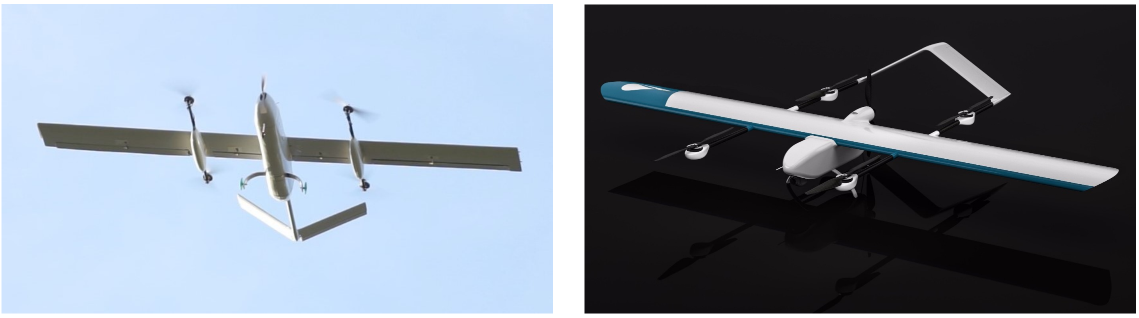
Figure 1: Operational costs

To do aerial inspections, some different drones can be used.

- Multirotor: These drones carry several motors on their bodies. They can stay in a stable position in one spot in the air for a long time, so they are a popular choice for aerial photography and surveillance.
- Fixed wing: the drone mimics the construction style of aeroplanes. These drones cannot stay in one place, but instead, glide on their set path for as long as their energy source permits.
- Convertible: these drones are fixed wings but with some specific motors to allow the vertical take-off and landing.

The convertible drone is the best choice because it can fly at high speeds but also can take-off and land in small places.

The company Venturi transformed an old fixed wing(VX1) to a convertible drone to do some tests and learn the weak points of this kind of drones. With all the information received, the company could start designing a new commercial prototype(V1).



(a) VX1 (b) Render of the V1

Figure 2: Molds for Yellowscan mount

CHAPTER 1. VENTURI UNMANNED TECHNOLOGIES

1.1. Company overview

Figure 1.1: Logo of Venturi Unmanned Technologies

The figure 1.1 shows the logo of the company.
Venturi aims to provide end-to-end solutions using drone technology. Our offer is focused on customer experience, from carrying out aerial inspection for reporting usage data.
High-resolution images are gathered using a drone, adapting its cameras and sensors according to customers' needs. Two models will be launched based on the power source selected: electric batteries and hydrogen system. These are the characteristics of the platform:

- Extended flight time:
  Up to 2 hours flight time using electric batteries and 8 hours thanks to the hydrogen power system.
- Added functionality
  No need for a runway. Operate everywhere thanks to the Vertical Take-Off and Landing system (VTOL).
- Analytics.
  Up to 4kg of cameras and sensors.
- Autonomous navigation systems.
  Automatic flight to cut down costs.
- Composite materials structure.
  Lightweight and extra performance.

At the moment, the company will be focused on the electric model.

Objectives of the company
The primary objective of Venturi is to become one of the most important companies in power utilities, mining, quarries and Oil-Gas inspections. The drone V1 that venturi is working in will be the platform that will do all these inspections.
The company will sell the drone and also will operate it for the companies that don't want to buy a drone but need the service.

1.1.1. Power utilities

Power utilities are also one of the significant potential markets for drone technology. So far, most inspections were focused on high voltage towers using multirotor ones. However, as time goes by and BVLOS operations are becoming more frequent, the possibility of studying the wiring network becomes an interesting point to cut down on costs and obtain digital data from these utilities.
Some of the current applications involving the power grid maintenance are listed:

- Vegetation-wiring distance calculation.
- Sag profile and tension calculation along wiring between towers.
- Hot spots detection.
- Technical projects regarding new facilities, earthworks. . .
- Digital elevation models.

Helicopter costs are much higher despite allowing the operation of heavier payloads. To be able to obtain thermal imaging, a conventional aircraft would not provide enough resolution, so the electric one could fly at a lower altitude to collect high-resolution data at a low operational cost. Also at was mentioned before the risks of the operation are lower because there are not human pilots in the aircraft. With all these reasons we can affirm that the use of a convertible drone is better than a helicopter.

Payloads for power utilities

- Electronic Optical sensor
- Thermal sensor
- LiDAR

1.1.2. Oil-Gas

Oil and gas pipelines inspection across North America, North Africa and the Middle East is a tremendous business opportunity.
The figure 1.2 show different networks among these areas. For instance, only in Europe, there are 200.000 km of gas pipelines, while the United States has built around 2.200.000 km combining oil and gas.
Safety standards in oil-gas are high, requiring strict compliance in all stages, from construction to inspection and maintenance. However, it is true that there is still a lack of standard procedures for unmanned aircraft.
The distance between pumping stations can be very variable, reaching up to 1.500 km in some cases. Typically, there is a distance of around 100 km. Generally, these pipelines are buried. Leak detection can be based on two different methodologies, inferential (internal) and direct inspection (direct).

External inspection using UAVs is based on differential thermal imaging of soil. Advantages of using this technique over inference one are obtaining the exact location of leaks, while reasoning works comparing isolated points flows and pressures. This system is centralised and monitored by computer software (SCADA).
Regular inspections have to be carried out with a frequency of around two weeks.
In some cases, such as in Emirates, companies are carrying out daily inspections with patrols for security purposes.
Regarding data resolution, a drone would fly at 100 m height, while a manned plane would fly at 1000 m.

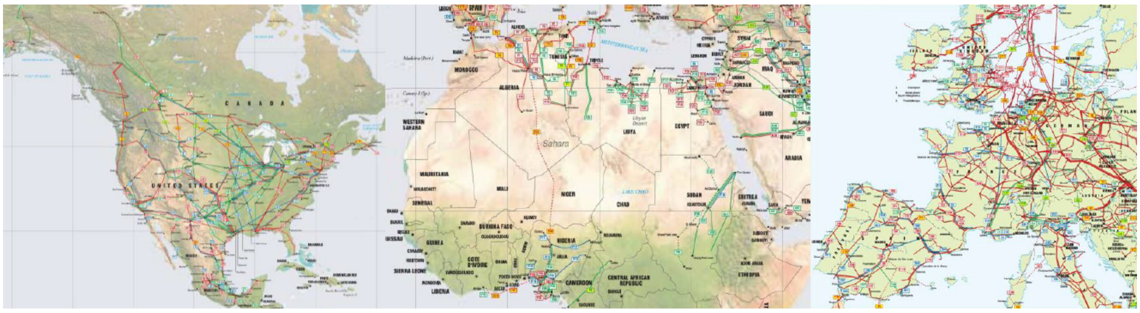


Figure 1.2: Oil and Gas distribution across North America and EMEA

Payloads for Oil and Gas
Expected payload capacity was around 4-7 kg for this range of UAV. Development of new cameras and sensors is allowing to reduce this weight progressively.
Generally, visual cameras are used to carry out surveillance inspections, while thermography is used to detect leaks and LIDAR systems create high accuracy maps to study soil movements and small deformations. The payloads used for Oil and Gas are the following ones:

- Electronic Optical sensor
- Thermal sensor
- LiDAR
- Gas sensor

1.1.3. Mining

The implementation of drones in the mining field has spread worldwide since it helps with processes from prospection to execution.
These are the main applications:

- Observation and prospection of operations.
- Control and monitoring of mineral extraction and its environmental impact.
- Monitoring of soil movements, residues, ponds, etc.
- Volumetric calculations of the extraction areas and stockpiles.
- Detailed map development to assist planning and design stages in new mining sites.
- Prospecting and searching of resources and mineral deposits.
- Topography exploration to identify the appropriate mining method and technology.
- Aerial inspection of the mining site to obtain detailed information for maintenance and risk prevention.
- Mining site restauration monitoring after the closing, through spectral analysis of vegetation and others.
- Drainage and flood analysis.
- Electric network planning.
- Radio link and communication planning.

Payloads for mining
Because of the capability of low altitude flight, it is possible to obtain higher resolution data with smaller and cheaper equipment compared to conventional aircrafts. The payloads used for Oil and Gas are the following ones:

- Electronic Optical sensor
- High Sensitivity Magnetometer
- Thermal sensor
- LiDAR

1.2. Machines used in Venturi

Venturi has got some machines to do the prototyping work easier. To create and test all the prototypes, a 3D Printer and a CNC machine are used. When the piece is tested and works well, it is prepared to create a final piece that usually is made with the CNC.

1.2.1. 3D printer

A 3D printer is a computer-aided manufacturing (CAM) device that creates three-dimensional objects. Like a traditional printer, a 3D printer receives digital data from a computer as input. However, instead of printing the output on paper, a 3D printer builds a three-dimensional model out of a custom material.
3D printers use a process called additive manufacturing to form (or ”print”) physical objects layer by layer until the model is complete.
The process of printing a 3D model varies depending on the material used to create the object.
The 3D Printer that Venturi has is the Sigma model of the company BCN 3D (figure 1.3). With this 3D printer, some different prototypes can be done to evaluate which one is the most suitable to be de definitive one. [1]

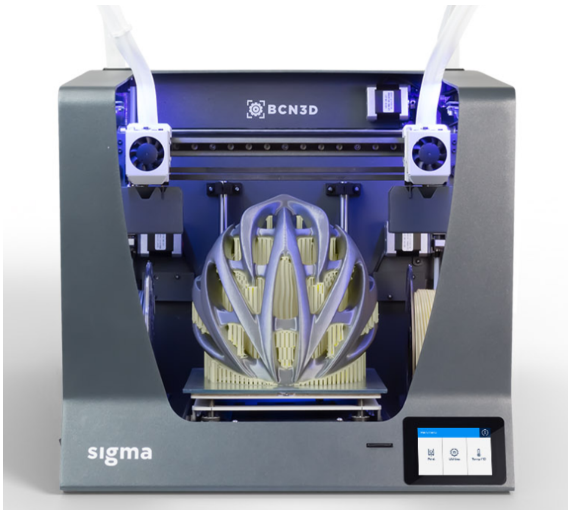


Figure 1.3: 3D printer. Sigma BCN 3D

The Sigma model that Venturi has, has the following properties:

- It's able to construct pieces with 210mm of width, 297mm of large and 210mm tall.
- It has two different extruders, one of 1mm and another one of 0.4mm of nozzle.
- The layer heigh may vary between 0.05 to 0.5mm depending on the nozzle diameter
- The resolution of the X and Y axis is 12.5 micrometers and the Z axis (vertical) is 1 micrometer.
- The software used for this 3D printer is the Cura-BCN3D where all the settings like the infiell, the temperatures or the support can be modified to obtain different versions of the same piece with different characteristics. [2]

1.2.2. Computer Numerical Control (CNC)

The CNC gives us the possibility to create the prototypes that are already designed with SolidWorks and the 3D printer. The CNC can cut some different materials. In Venturi, the prototypes are first usually made of wood and then when the prototypes are tested, and they are made by carbon fiber or other definitive material.

In fabrication, computer numerical control (CNC) is the automated control of machining tools (drills, boring tools, lathes) by means of a computer, in which a numerical control machine operates on a piece of material (metal, plastic, wood, ceramic, or composite) to transform it to precise specifications. Numerical control machines combine a motorised tool and a motorised platform with a control system, and operate by way of a computer which accepts graphical computer-aided design (CAD) files, and transforms the input CAD file into a sequential program of machine control instructions, which are then executed. [3]

The CNC machine that Venturi has in the workroom is the Stepcraft-2/840 (Figure1.4).
It allows processing a wide variety of materials, such as wood, thermoplastics, ABS, PE, PP, soft/hard PVC, Lexan, polyamide, Plexiglas, Carbon, non-ferrous metals and some elastomers/thermosets and mixed materials.

Figure 1.4: CNC machine. Stepcraft-2/840

The Stepcraft-2/840 model has the following properties:

- Integrated modular control electronics for an easy connection to the computer via USB or parallel interface.
- Stepper motors from Nanotec.
- Working Space (X,Y,Z): 600 x 840 x 140 mm.
- Overall Size (X,Y,Z): 750 x 970 x 510 mm. [4]

CHAPTER 2. FIRST PROTOTYPE

2.1. Vibration mount VX1

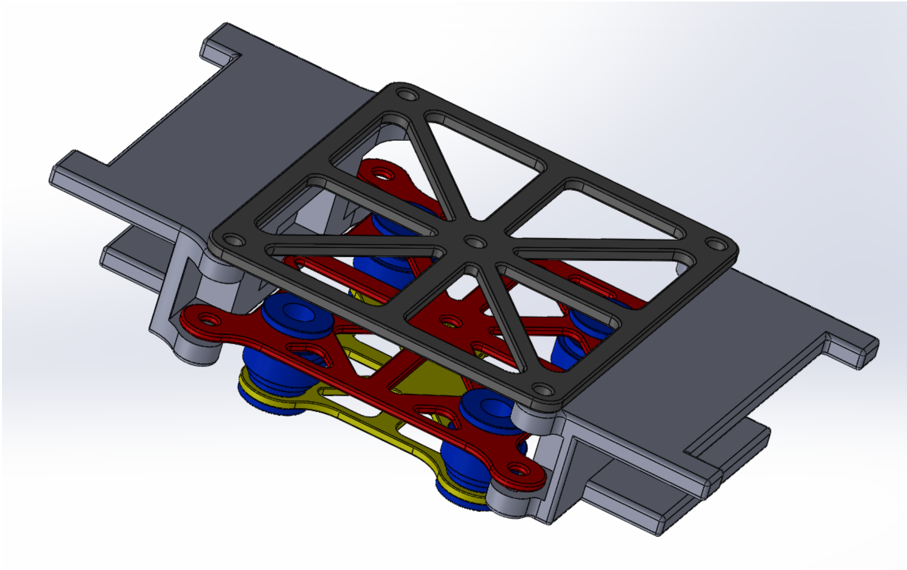


Figure 2.1: Damping system VX1. Final prototype

The VX1 is the first prototype that was constructed in Venturi. It was designed as an airplane, but finally, Venturi decided to operate it as a drone for inspection. They noticed the need for a convertible plane with VTOL to improve the take-off and landing. They made the VX1 compatible with the VTOL system.
This airplane showed the company all the weak points that needed to be solved to design the V1 (the final prototype) successfully.
After the market study of the different payloads, the Venturi team assigned to me the job of creating a vibration mount for a small EO cam for the VX1 (figure 2.1).
The VX1 had some vibrations, and the videos were not stable enough. The vibration mount improves the quality of the image avoiding and reducing all these vibrations.
Some things had to be taken into account to create this vibration mount:

- Study the structure of the airplane that should hold the vibration mount.
- Think about some solutions for this vibration mount.
- Design a prototype with SW.
- Print the prototype with the 3D printer.
- Improve the design.
- Create the definitive prototype.

The first task was to find the best place to install the vibration mount with the cam. Finally, the rear part of the airplane's body was the best choice.
To design the vibration mount, it was necessary to study the fixing of the frame to the aircraft.
The aircraft had two structural beams made by carbon fiber that was the best option to hold the vibration mount.
A prototype with this function can be built with different materials and forms, but all of these prototypes have the same components: top part of the mount, bottom part of the mount and the damping balls.
The top and bottom parts can have the design that each aircraft needs. However, the component that reduces the vibrations are the damping balls that can have much enforcement from gimbal isolation to protect sensitive electronics. They match perfectly with our wide range of isolation mounts and are available in many grams per ball vibration ratings identifiable by colours.

- Black=100g.
- Blue=150g.
- Yellow=200g.
- Red=300g

Figure 2.2: Damping balls

This freight is the maximum weight that each damping ball can carry to work in normal and stable condition.

2.1.1. Design in SolidWorks

The first step to do the design in SolidWorks was to create the union between the two main beams and the vibration mount. A rectangular structure was created to fit perfectly around the beams and to avoid the horizontal movement of two of the ribs of the main fuselage were used. With this design, the piece was stable and completely fixed.
The following steps were to create two mounts to hold the four damping balls.
To make the union of the damping system and the fixed structure, four screws were used to attach all the structure.

2.1.2. Make it real

The 3D Printer was used to create the prototype. The design was done with the extruder of 0.4mm and a high infield to achieve a robust piece.
Then when all the parts of the prototype were created, they were assembled to the fuselage. At this moment some errors were noticed. For example, the two fixing unions did not fit into the beams, and the design had to be modified, and new pieces were created to replace the wrong ones.
Furthermore another big problem was noticed: the different action cameras, depending on their size, did not fit inside the structure because of the different dimensions.
It was necessary to think a solution to solve the problem. A redesign needed to be done.

2.1.3. Redesign solving the problems

To allow the vertical movement and solve the problem of the different sizes, another fix mount above the structure was created. This mount had a screw connected with the top mount of the damping system. Screwing or unscrewing this screw, the damping system can be modified vertically to adjust the position of the camera.

The picture 2.1 shows how the system was designed and also the redesigned system with the vertical movement.

CHAPTER 3. PAYLOAD STUDY AND MARKET RESEARCH

Before starting to design the mounts of the payloads, all the payloads needed to be studied. The payload used to do a power line inspection is different from the payload used to mining tasks. A payload study had to be done for each of the functions that the drone is supposed to do.
The cameras and sensors that Venturi will use in the drone are the next ones.

3.1. LiDAR

Lidar is a laser-based method of detection, range finding and mapping.

Lidar typically uses a low-power, eye-safe pulsing laser working in conjunction with a camera. The laser illuminates a target, and the associated software calculates the time it takes for the laser to reflect back from the target. In some applications, specifically-tuned lasers may be used to excite and detect elements or compounds.

Lidar's best-known application is measuring the speed of a target, for example in police speed guns (one of the few non-eye-safe applications of the technology). Lidar is used in conjunction with GPS to yield three-dimensional (3-D) topographical maps by sweeping from a vantage point such as the underside of an aircraft. [5]

There are a lot of different LiDARs in the market, but not all are suitable to be carried in a drone flying at 70 kilometres per hour.

The table 3.1 show some LiDARs that was compared to choose the most suitable one to carry on the V1.

LiDAR	**Phoenix Scout**	**Riegl VUX-1LR 820kHz**	**Yellowscan Surveyor**	**HDL-32E**	**Riegl miniVUX-1DL**
Weight	1.6kg	3.5kg	1.5kg	1.3kg	2.4kg
Dimensions	160x116x116	227x180x125	100x150x140	144x85	232x99x121
Power consumption	40W	65W	15W	12W	40W
Input voltage	11-28V	11-32V		9-18V	11-34V
Laser range	120m	150m	100m	100m	
Resolution	2mm	10mm	30mm		10mm
Accuracy	30mm	15mm	50mm	20mm	15mm
FOV	360^o	330^o	360^o	360^o	46^o
Operational temperatures	-10^o to 40^o	-10^o to 40^o	-20^o to 50^o	-10^o to 60^o	-10^o to 40^o
Humidity	-	max 80% IP64	-	IP67	max 80% IP64
Aircraft velocity	18 to 144 km\h	20 to 140 km\h	15 to 100 km\h		65 km\h

Table 3.1: LiDAR comparison

The previous table shows some of the essential characteristics of the different LiDARs that were studied. The most critical parameter is the number of shots per second and also the accuracy and resolution. Another thing that should be taken into account is the price and if the product is available to be rented. In the beginning, the LiDARs should be rented because of the cost. This technology is costly.
Also, the company had contact with the companies Yellowscan and Riegl, and this had to be taken into account because of the facilities that these companies offered to Venturi.
The Riegl Vux-1LR 820kHz is too heavy for our drone, so this LiDAR was rejected. For these reasons, the LiDARs that were chosen as the bests to be carried in Venturi's drone are the Riegl Minivux 1DL and the Yellowscan Surveyor.
Yellowscan recently has created a new LiDAR called Surveyor Ultra that has complete specifications for the operations that Venturi has to do.

3.2. Optical cam

An optical sensor is a device that converts light rays into electronic signals. Similar to a photoresistor, it measures the physical quantity of light and translates it into a form read by the instrument. One of the features of an optical sensor is its ability to measure the changes from one or more light beams. This change is most often based around alterations to the intensity of the light. Optical sensors can work either on the single point method or through the distribution of points. Through the single point method, a single phase change is needed to activate the sensor. Concerning the distribution concept, the sensor is reactive along a long series of sensors or single fiberoptic array. [6]

In the beginning, the idea was to carry an EO sensor, an FPV camera and a Thermal sensor but because of some reasons that will be explained later, a turret that already includes the EO and the thermal sensor had to be selected. The company UAV Vision with the CM series and the company DST with the OTUS series were compared to determinate the most suitable turret.
The tables 3.2 and 3.3 compare between the different models of each brand.

EO	**CM100**	**CM160**	**CM202**
Weight	800g	1450g	3500g
Diameter	100mm	160mm	190mm
Heigh	129mm	237mm	295mm
Humidity	IP63	IP66	IP66
Power consumption	12W	20W	55W
Voltage	9-36V	9-36V	9-36V
Temperature	-10^o to 50^o	-10^o to 50^o	-10^o to 50^o
Position accuracy	0.022^o	0.011^o	0.0046^o

Table 3.2: EO comparison. CM sensors

EO	**OTUS U135**	**OTUS L170**	**OTUS U205**
Weight	1400g	2300g	2600g
Diameter	135mm	170mm	205mm
Heigh	186mm	243mm	275mm
Humidity	-	-	-
Power consumption	15W	20W	20W
Voltage	18-36V	18-36V	18-36V
Temperature	0^o to 50^o	0^o to 50^o	0^o to 50^o
Position accuracy	0.36^o	0.036^o	0.036^o

Table 3.3: EO comparison. DST sensors

Finally, the dimensions, the weight and the accuracy were the specifications that were taken into account to make the selection. The turret selected was the CM 100.

3.3. Thermal cam

An infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing you to not only monitor thermal performance but also identify and evaluate the relative severity of heat-related problems. [7]

IR/THERMAL	**Saitis 2-640**	**Saitis 640**	**Vue Pro 640**	**Quazir HD+**
Weight	54g	22g	113g	453g
Dimensions(mm)	42x42x36	27x27x26	63x44.4x44.4	57x66x70
Spectral Band	8-14um	8-14um	7.5-13.5um	MWIR
Pixel Pitch	17um	17um		12um
Resolution	640x480	640x480	640x512	1280x1024
Display format	PAL-NTSC	PAL-NTSC	PAL-NTSC	720p 1080p
Frame rates	9,25 or 30hz	9,25 or 30hz	25 or 30hz	60hz
Temperature	-40^{o} to 60^{o}	-40^{o} to 60^{o}	-20^{o} to 50^{o}	-40^{o} to 75^{o}
Power dissipation	1W	1W	2.1W	

Table 3.4: IR/THERMAL comparison

The most important specification of the thermal sensor as well as in the EO sensor is the capacity to obtain a right frame flying at 70km/h. The precision and accuracy are essential to capture this frames too.
In the table 3.4 there are some excellent options for thermal sensors, but we noticed that there were some dimension problem.
That is the reason because all these thermal sensors were not an option and the final option was the sensor that the turret CM100 includes.

3.4. Turret EO-Thermal sensors

The drone should carry an electro-optical and a thermal sensor that focuses at the same time at the same point to be able to analyse for example the power lines to find hotspots. This two sensors will need a gimbal system to be able to follow a cable and reduce the vibrations and movements of the plane. If the sensors are too big, the gimbal needs to be very big, and it is a problem for the drones dimension.
A thermal and electro-optical sensor was chosen following the specifications, and a gimbal was designed to check if it was a solution. Afterwise we noticed that the SolidWorks model was not an option.

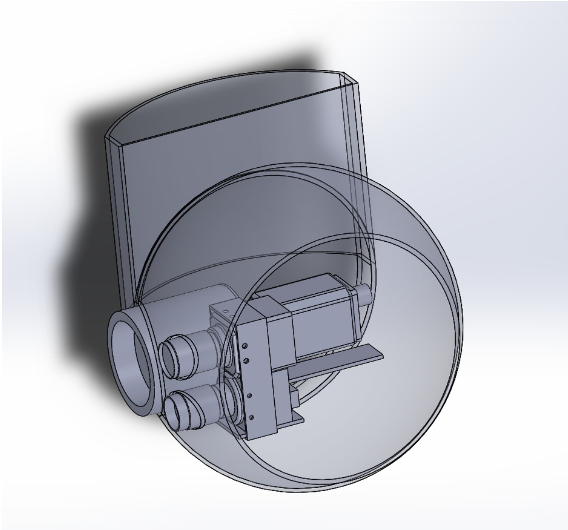


Figure 3.1: Gimbal with EO and thermal sensors

Only the dimensions of the ball were 25cm of diameter, so including the two arms with the motors for the gimbal movement, we could determine that the structure was too big for the drone and too complicated to construct this gimbal 100% custom.
Identifying all this information, a solution had to be found, and the use of an existing turret was the best option. The turret CM100 and CM122 (an improvement of the CM100 model) has a thermal and EO sensor. The specifications of the sensors that this turret includes is worse than the specifications of the gimbal system designed before, but it was enough for the operations that the drone has to do. Also, the CM turret has all the software to process the data and is cheaper than the homemade turret with all the sensors.

3.5. Gas sensor

Recently, the company studied new market opportunities and the gas sensor is an excellent solution to enter a new market.
The new sensor can inspect the pipelines, the ones that are on the ground and the ones that are buried, helping us to detect leakages of methane.
The gas sensor is a sophisticated sensor that also includes an electro-optical cam and is connected to the GPS of the drone.
The electro-optical cam is recording during the operation and allows to receive the image in real time. When the image is processed after the flight, the output is a screen showing you the video and also the thermal image that detect the leakages. With this two outputs, you can see where the leakages are and even the environment around the leakage adding to this the position due to the GPS connexion. The sensor also includes a cooling system because of the sensitivity of the sensor.
As can be seen in the contents there is not a specific mount for this sensor. The reason is that the intentions to carry this sensor is very recent. The mount of the gas sensor will be designed soon.

CHAPTER 4. MOUNT FOR THE LIDAR MINIVUX 1DL

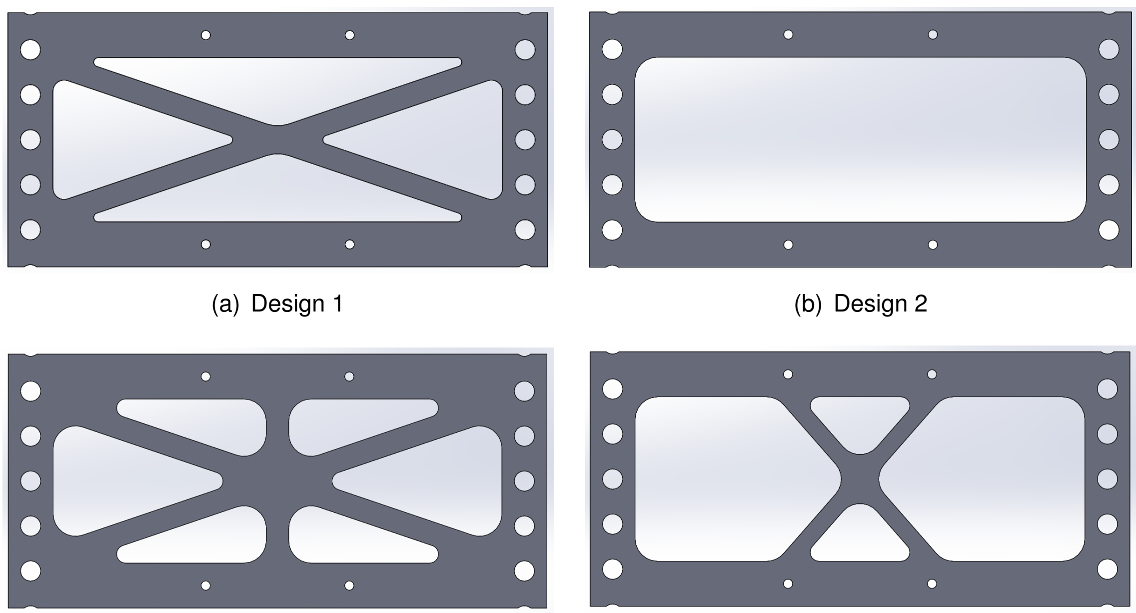
4.1. Analysis of the LiDAR information

The first step was to study all the information received from Riegl to know what the LiDAR needs to design the most suitable mount.
The Minivux 1DL cannot be carried in a gimbal; it only requires a damping system to avoid as many vibrations as possible.
The LiDAR that venturi wanted to use had an electro-optical cam (Sony a6000) to add the colours to the mapping obtained. This cam also adds some extra weight and makes the payload bigger. The size of the payload is a real problem because a big damping system will be needed.
The components of the damping system are similar to the first prototype of a damping system that was made for the VX1. The mount consists of two parts, the top and the bottom one, as well as some damping balls. To hold the two mount parts, a system of ribs that are attached to the fuselage was designed. With six ribs for each side and some supports for the bottom mount, the damping system is well fixed.
The payload weights 2.8 kg, and the damping balls that will use can carry 300gr each one. To be sure that the system will fix the payload even in the turns when there are G-forces, the system is over-dimensioned to 6.6 kg. The damping balls can carry 300g, so 22 damping balls will be needed for this mount.

Figure 4.1: Riegl Minivux 1DL APX15 UAV

4.2. Design of different mounts

In the appendix A, there are all the sketches with all dimensions of each part of the mount. One of the most essential requirements for the LiDAR mount is that it should be as lightly as possible. With this requirement, some different designs were made and also tested to know which one is the best to fix the LiDAR. The figures 4.2 show the four different models of mount that were created and tested.



(a) Design 1

(b) Design 2

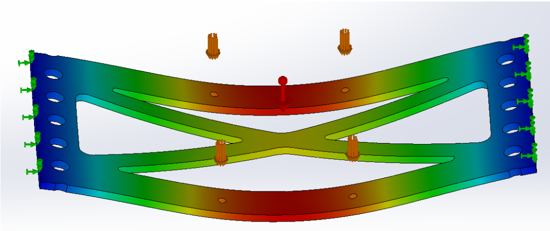
(c) Design 3

(d) Design 4

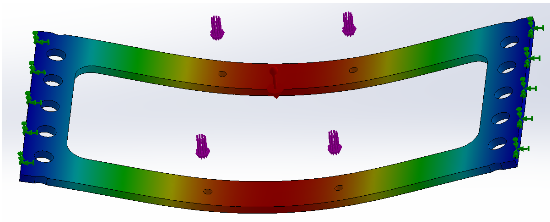
Figure 4.2: Different designs for the Minivux 1DL mount

4.3. Study of stress and deformations with SW

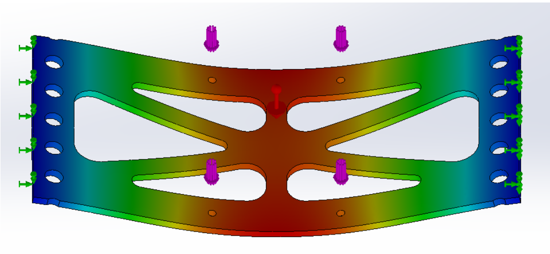
The best way to determine what was the most resistant design was to do a static test. The SolidWorks can do a deformation and stress analysis.
The next pictures show the deformation results of the analysis.



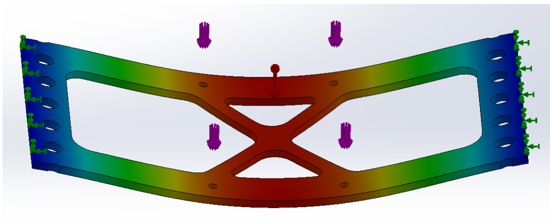
(a) Design 1



(b) Design 2



(c) Design 3



(d) Design 4

Figure 4.3: Deformation test. Minivux 1DL mount

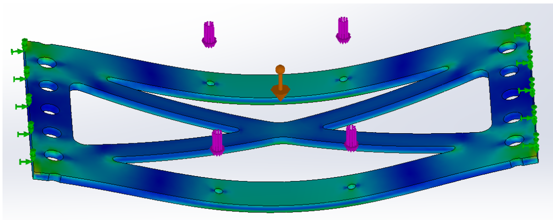
As can be seen, the designs three and four have a better distribution of the deformation. The distribution of forces can be seen with the different colours on the figures 4.3. With this information, the models one and two can be rejected.
The table 4.1 there are the numeric values of this deformations.

Design	Deformation (mm)*
Design 1	0.022312
Design 2	0.028562
Design 3	0.020636
Design 4	0.025909

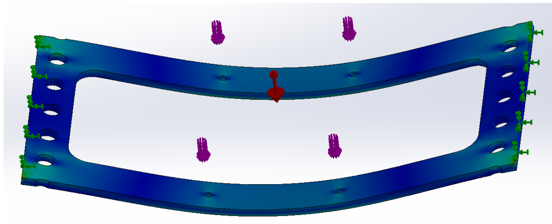
Table 4.1: Deformation test results. Minivux 1DL mount

The results show that the design with less deformation is the number 3.
*The results that the program show are not real because the density of the carbon fiber that the program has, will not be the same as the density of the carbon fiber that will be used. The test is only qualitative.

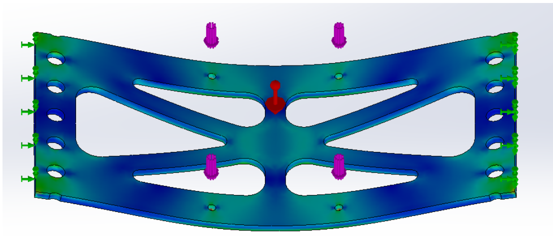
The most important test is the stress test because of it will determine which structure is the most resistant.
The nexts pictures show the stress results of the analisys.



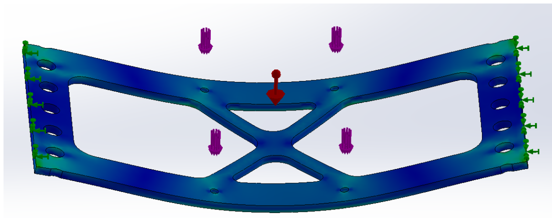
(a) Design 1



(b) Design 2



(c) Design 3



(d) Design 4

Figure 4.4: Stress test. Minivux 1DL mount

In the following table there are the numeric values of this stress.

Design	Stress (N/mmˆ2)*
Design 1	10720496
Design 2	21668802
Design 3	10174530
Design 4	18728218

Table 4.2: Stress test results. Minivux 1DL mount

As in the deformation test, the design that shows better characteristics is the number 3.
*The results that the program show are not real because the density of the carbon fiber that the program has, will not be the same as the density of the carbon fiber that will be used. The test is only qualitative.

4.4. Experimental study of the prototypes made by wood

After the analytic study with the software SolidWorks, all the designs were made of wood on a 1/2 scale to do an experimental test (figure 4.5). The preliminary test consists in carrying 4kg to check that the designs are resistant. All the models did not break with the 4kg.

Some things should be taken into account; this experimental test was made with wood that is not the material that will be used for the final prototype. The wood is a good solution to see the design is outside of the computer. It also is a cheap material to do the first tests.

When all the information about the designs and the experimental tests was analysed, it could be affirmed that the design number 3 was the most suitable one to fix the LiDAR.

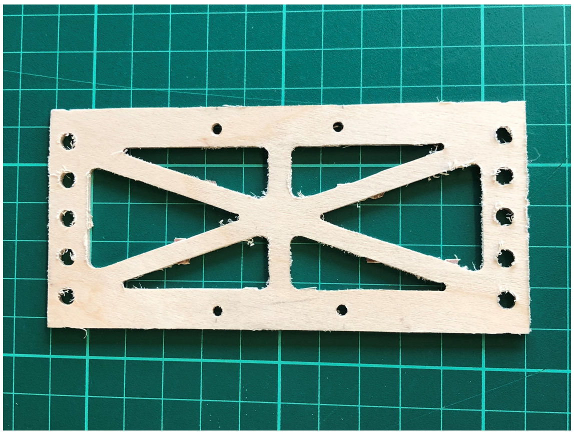


Figure 4.5: Minivux 1DL mount assembly

4.5. Carbon fiber prototype

The prototype can be made with different materials, each one with different properties. To choose the best material for this part, first, it is important to know the requirements of the mount.

- As lightly as it is possible.
- Strong and safe.
- Easy to assemble and disassemble.

The material chosen was the carbon fiber because of its low density, and it's higher resistance.
To create the prototype, the CNC was used to cut all the pieces with a carbon fiber sheet of 2mm of thickness that is more than enough for the LiDAR mount.
The 12 ribs, the rib top mount part, the bottom mount part and the top mount part were cut and assembled with the 22 damping balls to obtain the Final prototype of the Minivux 1DL mount 4.6.

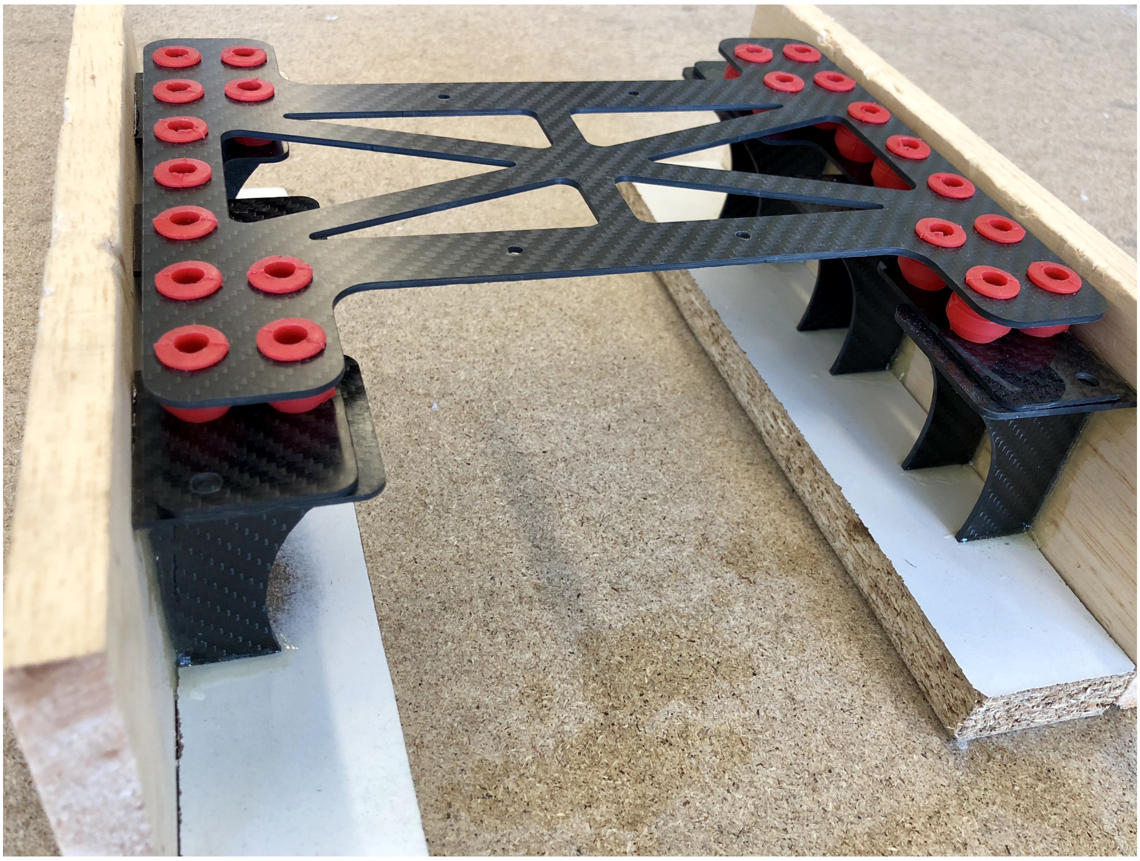


Figure 4.6: Minivux 1DL mount assembly

CHAPTER 5. CM100 (OPTICAL AND THERMAL CAM)

5.1. Analysis of the turret information

The first step was to study all the information received from UAV Vision to know what the CM needs to design the most suitable mount.
To obtain the thermal image and the optical image, the CM100 or CM122 (that are very similar) is the best choice.
The first step is the same as in the Minivux. The information received from UAV Vision that are the manufacturers of the CM series need to be studied and analysed. The CM series are turrets that include the two sensors and also the two-axis gimbal.
Even though the CM is a gimbal, it needs a damping system to reduce all the vibrations generated by the motors and the air.

5.2. Design a prototype in SW

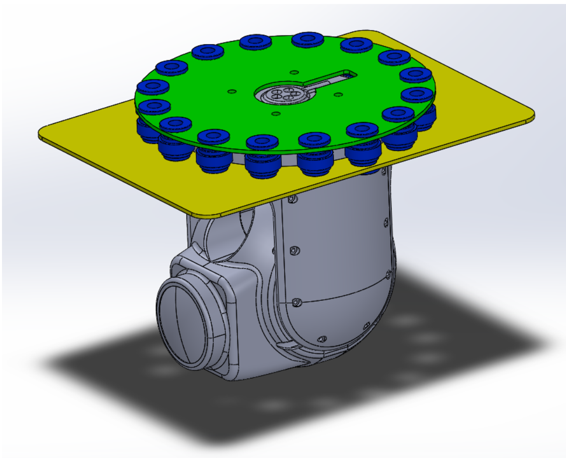


Figure 5.1: Sketch CM100. Assembly

The damping system is composed of a top mount and a bottom mount. The design of this mounts was made with the information received from the manufacturers, and it was very similar to a mount that UAV Vision has.
The top mount has all the holes to fix the CM and also the hole for the data and AC connection to plug all the cables in. There are also the holes for all the damping balls.
The bottom mount is simpler than the top mount because there aren't any cable crossing it and the CM is not fixed in this mount. The bottom mount has a big hole in the middle to be able to place the turret to the top mount and also the holes for all the damping balls.
The union between the two mounts are the damping balls. For this case, the black damping balls will be used to hold the turret. The black damping calls can carry 100g each one, so all together can carry 1.6kg that is more than the weight of the turret.

With this simple design, the CM will have a damping system, and it will be very light.
In the Appendix B there are all the sketches with the dimensions for all the components of the mount.
A stress and deformation study is not necessary in this case because of the simplicity of the mount, and the damping balls are very close to the turret. Also if the damping balls failed, the turret would not fall to the ground because of the anchorage method.

5.3. Do the prototype made by wood

The first prototype was made of wood to check the functionality and to be sure that all the holes and details are well designed.
The mount is composed by the top mount, and the bottom mount and both were cut with the CNC machine and assembled to obtain the first prototype of the CM mount 5.1.

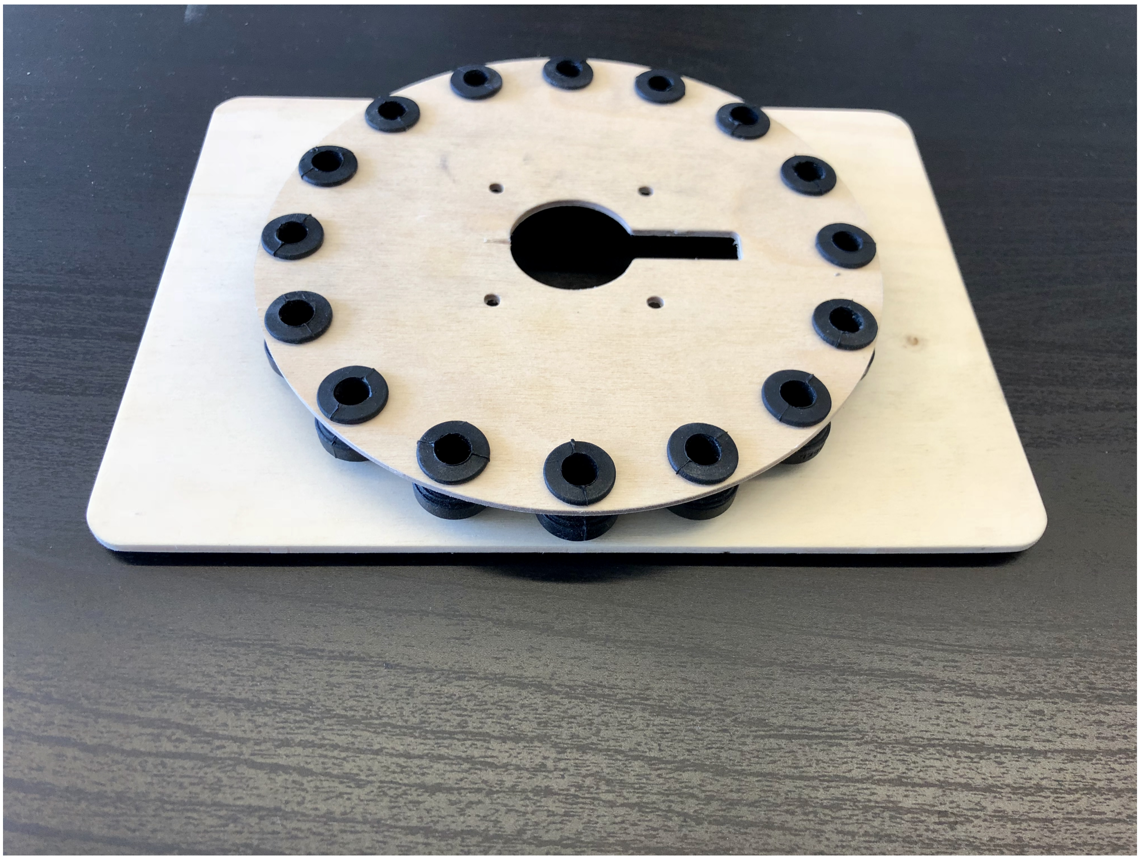


Figure 5.2: Wood prototype. CM mount

5.4. Next steps

The next steps to finish the CM mount are the following ones:

- Integration study.
- Carbon fiber prototype.
- Experimental tests with the final prototype.

The next step consists of doing the final version of the bottom mount.
The top mount that is already designed is a final version, but the bottom one is only a first version. The reason of this version is because the rips of the fuselage are not defined, so its impossible to place the holes to attach the bottom mount to the fuselage.
When the design is finished, the prototype will be cut in a carbon fiber sheet of 2mm with the CNC machine like the LiDAR mount. The material chosen here is the carbon fiber because the mount has the same requirements as the LiDAR mount, so the most suitable material is the carbon fiber.
The last task to affirm that the mount can be placed in the aircraft is to do an experimental test with the definitive mount to check the resistance and the final weight.

CHAPTER 6. YELLOWSCAN SURVEYOR

6.1. Analysis of the LiDAR information

The Yellowscan Surveyor is another LiDAR that the drone should be able to carry.
The first step was to make contact with the company Yellowscan to receive all the indispensable information about the product to make the mount as better as possible.
The LiDAR, like with the Minivux 1DL, must not have any gimbal, it only can be fixed in a damping system to avoid as many vibrations as it is possible.
There are two versions of this LiDAR, the Yellowscan Surveyor and the Yellowscan Surveyor Ultra. 6.3
The idea is to carry the Ultra version but is very new, and right now it is difficult to rent it. The LiDARs that Venturi will use are rented because of the price that it has. All these devices are very expensive, more than 100.000 euros.
For this is the reason because the Surveyor Ultra is not an option now.
The difference in size between one and the other is very similar, and the anchorage method is the same, so only one mount needs to be designed.
The specifications of the Yellowscan Surveyor are the following ones:

- Precision: 4 cm.
- Absolute accuracy: 5 cm.
- Laser scanner frequency: 300 kHz.
- 300k shots/s
- Weight: 1.6 kg battery included.
- Power consumption: 15W.
- Autonomy: 2 hours.
- Size (mm): 147 x 104 x 138.

The Yellowscan Surveyor Ultra has the following specifications:

- Precision: 5 cm.
- Absolute accuracy: 10 cm.
- 700k shots/s
- Weight: 1.7 kg battery included.
- Power consumption: 19W.
- Autonomy: 1.2 hours.
- Size (mm): 165 x 104 x 138.

As you can see the precision and the accuracy of the Surveyor is better than the Surveyor Ultra, and that is because of the different shots per second. The Surveyor Ultra has more than the double, and this is very important because of the speed of the drone. The results of the Surveyor Ultra will have a better definition than the results of the Surveyor.

Figure 6.1: Yellowscan Surveyor Ultra

Before starting to design the mount, Venturi received some information from Yellowscan. Like in the Minivux, the Yellowscan only needs a damping system. It can not be placed with a gimbal.

6.2. Firsts designs with SW

The yellowscan mount is composed by a top mount that is already designed, and a bottom mount will be fixed to the fuselage. This bottom mount is not developed yet because the ribs of the fuselage are not defined.
The union between the two mounts are the damping balls. For this case, ten red damping balls will be used to be sure that the LiDAR is well fixed. This ten damping balls can hold 3kg, almost the double of the weight of the LiDAR.
In the appendix **??** there are all the sketches with the dimensions of each component of the mount.
The most simple design is an ”L” design, and it is the one that was used for the top mount. The ”L” is inverted to use the top part for the damping balls and the large part to fix the Yellowscan Surveyor or the Yellowscan Surveyor Ultra.

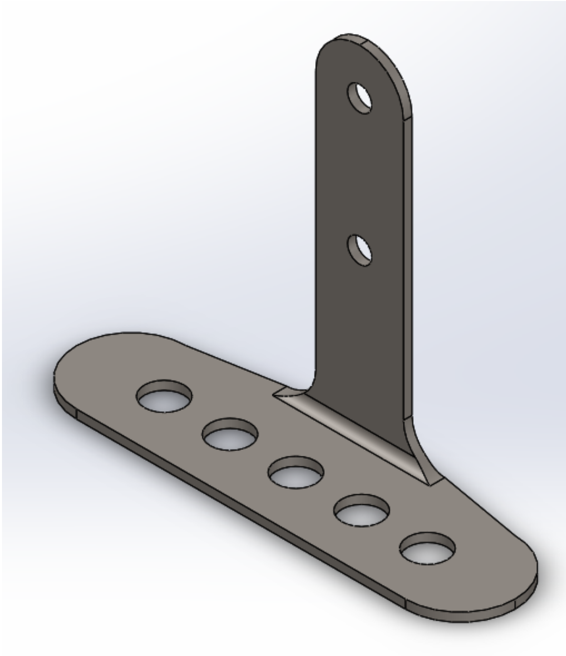


Figure 6.2: SW design mount. Yellowscan Surveyor Ultra

6.3. Analitic study of forces with SW

To be sure that the ”L” design mount is strong enough, an experimental test should be done, but the first interesting thing to do is an analytic study with the SolidWorks to determine the weak points of the design.
As with the Minivux mount, the research is only qualitative because the properties of the material used are not the same than the properties that the SolidWorks has.

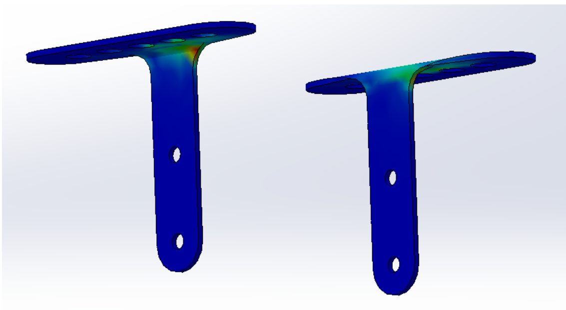


Figure 6.3: Stress test. Yellowscan Mount

Before beginning to design the ”L” mount, the weak point that was expected was exactly the point that SolidWorks had shown. Because of this reason, the radius where the weak point was placed, was modified to do it bigger to support better the forces.
However, the real test is the experimental one, and to be able to do it, a real prototype should be created.

6.4. Glass fiber prototype

The prototype that needs to be created is the first prototype, so it should be done with a cheap but resistant material. The material that was chosen for this prototype was the glass fiber that is cheaper than the carbon fiber (the final material) but is resistant enough to test it. If the glass fiber prototype can resist the weight of the LiDAR, for sure that the carbon fiber that is stronger than the glass fiber will hold it.
The figure 6.5 you can see the glass fiber prototype.
To do the glass fiber prototype with the method of lamination, a mold had to be created. The mold was made with the 3D printer, and then some steps should be done to prepare the molt before the lamination.

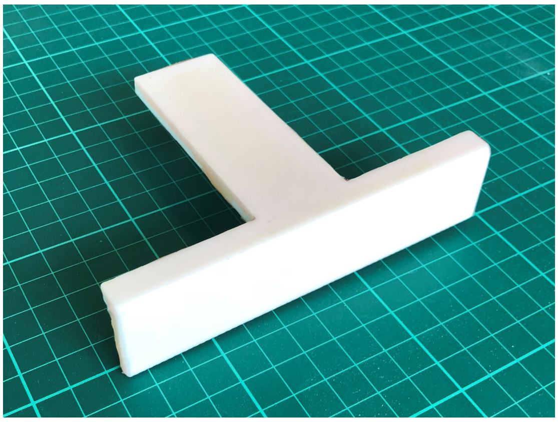
- Clean all the surface.
- Apply a glass coating.
- Use sand papers to level all the surface and remove all the scratches.
- Clean all the surface with a cleaning agent.
- Apply two different pulishments to make it brilliant.
- Clean it again.
- Apply some layers of a dismolding agent.

When the mount is prepared, the lamination can be started.
The first prototype was made with seven layers of glass fiber to check the form and the resistance and to see if there are any other weak point.

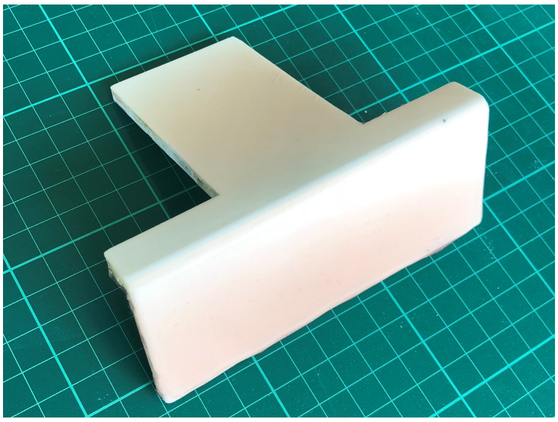
6.5. Improvement of the design

When the design was finished, some parts of it could be improved. The first thing that was noticed was that the radius of the weak point that was mentioned in the previous section continued being too small and also the space between the holes of the damping ball and the edge of the prototype was too small, and it could be another weak point.
To solve all these problems noticed, another mold was created to be able to do another piece with all these parts improved. The design was the same, but the mold was a little bit bigger to be able to create a bigger prototype.

The figures 6.4 show the two molds to see the differences.



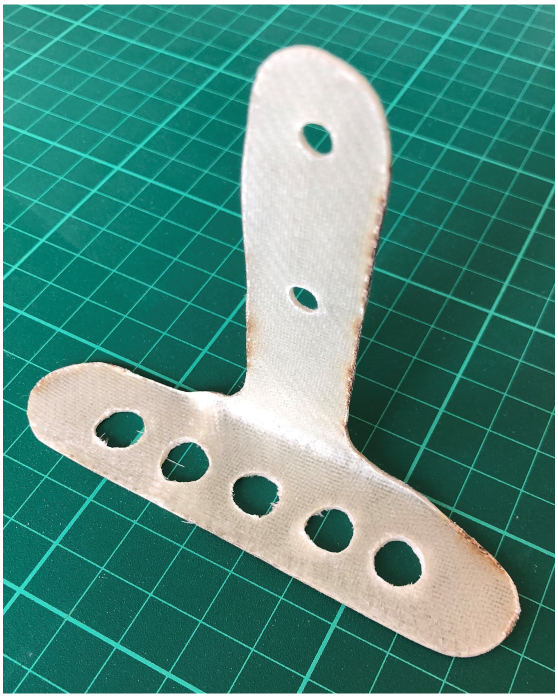
(a) Mold 1



(b) Mold 2

Figure 6.4: Molds for Yellowscan mount

With the bigger mold, the problems of the first prototype could be solved and also the new one was laminated with more layers of glass fiber, so it is more resistant and robust than the first one. With the next figures, the differences between the two models can be noticed.



(a) Mount 1

(b) Mount 2

Figure 6.5: Yellowscan mount. Prototypes

6.6. Next steps

Some things should be done to finish the mount of the Yellowscan LiDAR:

- Design the bottom mount.
- Do a prototype and test it.
- Make the two mounts with carbon fiber.
- Experimental tests with the final prototype.
- Mount it in the drone.

CHAPTER 7. COVER UNION MOUNTS

7.1. Anchorage methods

The drone will have some covers to be able to change some moveable parts like the batteries to place the CG (Center of Gravity) well or change the payload. For example, if you have to inspect power lines, you have to do two different flights, one with the LiDAR and another with the thermal and electro-optical sensor.
All these covers should comply with the following requirements:

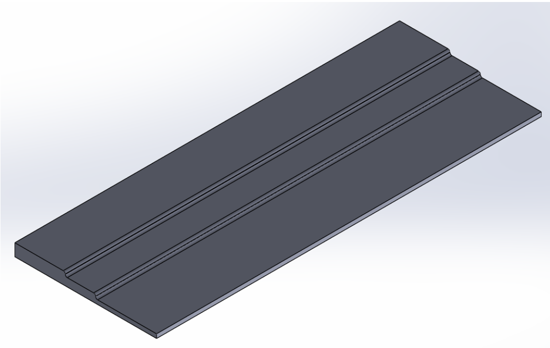
- Easy and fast assembly.
- Well fixed.
- Water resistant to not damage the electronic parts of the drone.
- Leveled with the rest of the fuselage.

There are many systems to anchor a cover, but maybe the best one is the quarter turn screw 7.1. This kind of screws are speedy to assemble and disassemble, and also they offer an excellent resistance, two of the essential requirements previously mentioned.
To solve the problem of the water resistance, a rubber seal will be used.

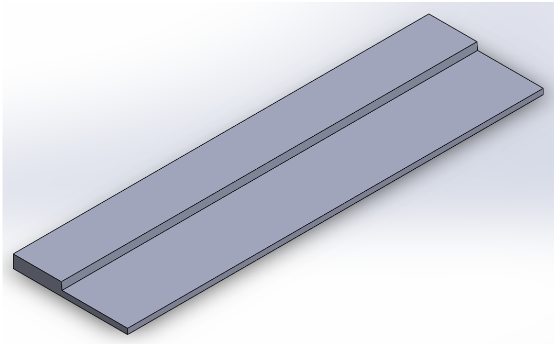
Figure 7.1: Quarter turn screw

7.2. Model design

The design was done with the SolidWorks and to complete all the requirements, the model used mirrors the one of a step. The upper step is the level of the fuselage surface, and the bottom step is where the cover and the rubber seal is supported.



(a) Model 1



(b) Model 2

Figure 7.2: Different designs for the cover

7.3. Glass fiber prototype

A glass fiber prototype was created with the method of lamination to test the design made by SolidWorks.

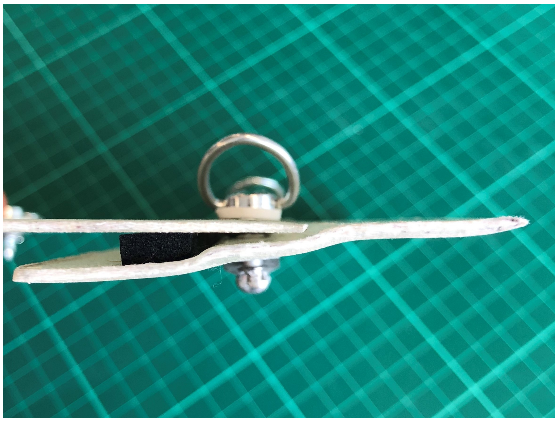
The prototype has eight layers of glass fiber that is more than enough to do all tests needed. The anchorage method as mentioned before is the quarter turn, and some different quarter turn screws were tested to check the torque and also if the surface is levelled with the fuselage

Some rubber seals were bought, with different thickness and width to find the most suitable way to place it and achieve the water resistance needed.

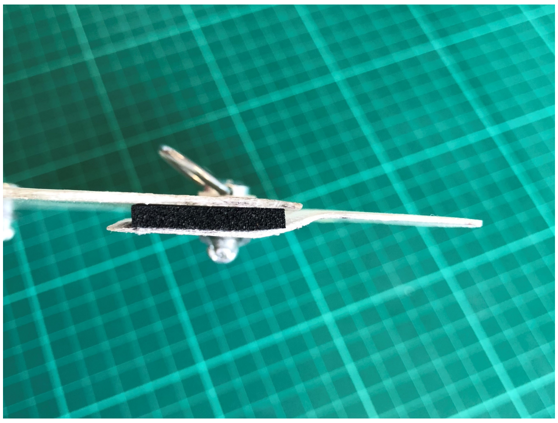
For the first prototype, the model design had three steps, the top one for the surface level, the middle one to support the cover and the bottom one to place the rubber seal. The rubber seal used had 4mm of thickness and 9mm of with.

Some problems that will be mentioned after were detected with this design.

The second and final prototype has only two steps, and the rubber seal is also different to improve and solve the problems of the first prototype. The rubber seal has a 3mm thickness and 20mm of width. The difference between the first and the second prototype is that the quarter turn screw is placed in the rubber seal.



(a) Cover 1



(b) Cover 2

Figure 7.3: Different prototypes for the cover

As seen in the picture, the second model of the cover looks much better than the first one. Some experimental tests were done to check the water resistance, and both covers react well against water. The problem of the first cover is the bending of the structure because of the rubber seal. The quarter turn is placed next to the rubber seal and the pressure that is applied to fix the cover in contact with the rubber seal make this bending. In the second prototype, this problem does not appear because the quarter turn is in the middle of the rubber seal and it makes that the pressure of the torque is well distributed to all rubber seal.

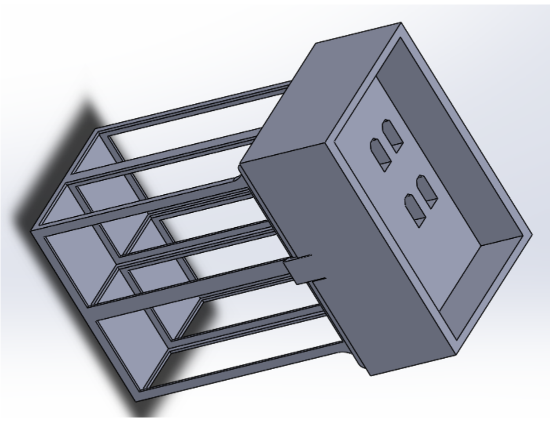
CHAPTER 8. OTHER LABORS IN VENTURI

8.1. Study of a battery support

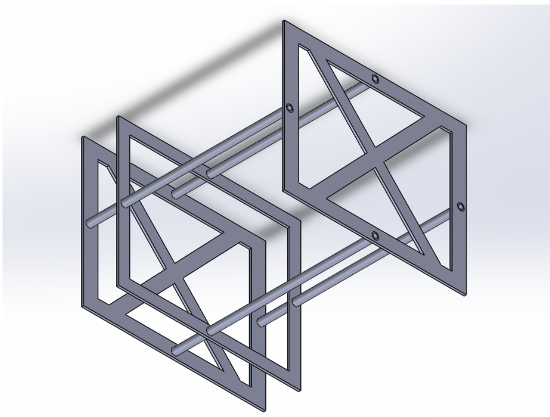
In the beginning, the drone should be powered by four lipo batteries of 12000mA, two in serie and two in parallel. These batteries cannot be moving inside the drone during the flights, so battery support should be made.
The support should follow the next requirements:

- Low weight.
- Battery connectors XT150.
- Durable and resistant.
- Easy to install and remove.
- Batteries well fixed.

Two different solutions were designed knowing the requirements.



(a) Battery support 1



(b) Battery support 2

Figure 8.1: Different designs for the battery support

The first support was too heavy, so a second support simpler were designed to reduce this weight and also do the mechanism simpler.
All these supports finally will not be used because other batteries were found to increase the flight duration and reduce the weight of the same batteries.

8.2. Wing union

Another problem with the VX1 was that too much time was needed to assemble the wings. The wing union of the first Venturi's drone was very complicated to be assembled. Four screws were needed and also sometimes it had problems of alignment.
The new drone should be able to be assembled without any screw and in only five minutes. To achieve this goal, a fast and simple wing union had to be designed.
If the design has all the union mechanism inside the same wing, it will not lose any aerodynamic point, so this was the beginning point.

8.2.1. SW model

A lever mechanism was created because is very easy and fast to be assembled. In the following picture, there is the model that was designed.

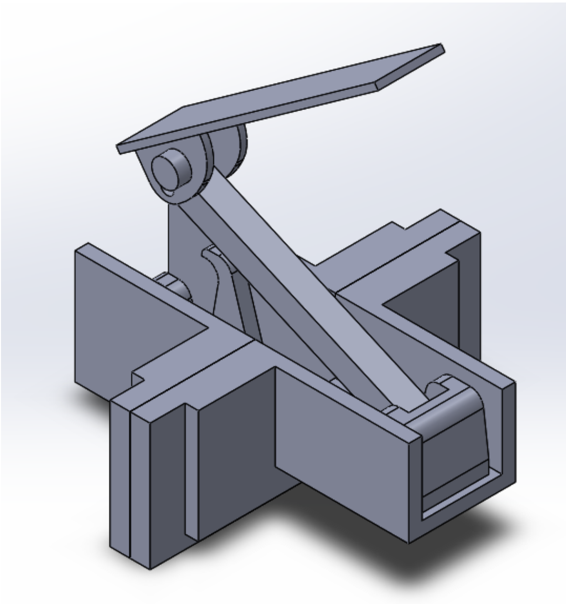


Figure 8.2: Wing union mechanism

The mechanism is very simple but is all custom. To adapt the prototype to the plane will need a lot of time and work. Now the company can not expend this time and hours of work to develop it, so we decide to use an existing model similar to the one that was previously designed for the first units of the drone.
In the future, a custom model like the one that was designed will be implemented to the drone.

8.3. Carbon fiber tubs union

The carbon fiber tubs union is an essential part because the tubs should be fast and easy to assemble. The easiest way to assemble two carbon fiber tubs without losing resistance is through the method of the ping. In the next picture, a ping method will be shown.

Figure 8.3: Carbon tube union mechanism

8.3.1. Cables connexion

All the cables will cross the wings inside the carbon tubes. Before assembly the two wings using the carbon tubes as a guide, the cables connexion need to be done. To be sure that any cable will be lost inside the carbon fiber tube, a 3D printed piece 8.4 was created to hold the two XT150 (power supply cables) and also the pin cable that will control all the servos.
This piece fit inside the small part of the tube and also has an O-ring to improve the water resistance.

Figure 8.4: Cable connector

As you can see in the previous picture, the piece has two screws. That is because two parts compose the piece, one fixed to the tub and the other can be assembled or disassembled to change a connector if it's broken.

CONCLUSIONS

Venturi is a company that is creating a drone for aerial inspection. To be able to do these inspections, the drone that venturi is forming has to be able to carry different payloads depending on the task that has to do.

A payload study and market research were done to define witch payloads were the most suitable to be carried in the drone. Finally, two LiDARs, one turret with electro-optical and thermal sensors and a gas sensor to detect methane leakages were chosen.

To be able to carry all these payloads, the mounts that will fix the payload to the drone had to be designed and created.

Also, some other labours were done in venturi, the battery support and the wing union will not be used by the moment, but the carbon fiber tub union and the cable connector was created and tested to be added to the drone.

The tasks in Venturi do not finish here; there is much work remaining to carry cams like the gas sensor, the CM turret and the Yellowscan surveyor. However, for sure that this work will be done, and the drone will flight will all these payloads to become a reality the dream of all workers od the company.

ACRONYMS

BVLOS	Beyond Visual Line of Sight
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
CG	Center of Gravity
EO	Electro-Optical sensor
FOV	Field Of View
LiDAR	Laser Interferometry Detection And Ranging
SW	SolidWorks
VLOS	Visual Line of Sight
VTOL	Vertical Take-Off and Landing
VX1	First ptototype designed by Venturi
V1	Final prototype designed by Venturi

BIBLIOGRAPHY

1 3D printer definition. (2018, July). Techterms. Retrieved 01 August 2018,
available at: https://techterms.com/definition/3d_printer

2 3D printer specifications. BCN 3D. Retrieved 01 August 2018,
available at: https://www.bcn3dtechnologies.com/ca/3d-printer/bcn3d-sigma/

3 CNC definition. (2018, July). Wikipedia. Retrieved 11 August 2018,
available at: https://en.wikipedia.org/wiki/Numerical_control

4 CNC specifications. Stepcraft. Retrieved 11 August 2018,
available at: https://www.stepcraft.us/dseries

5 LiDAR definition. (2013, September). whatis. Retrieved 15 August 2018
available at: https://whatis.techtarget.com/definition/Lidar

6 Ahuja, Dhiraj; Parande, Deepa. (2012).Optical sensors and their applications.
Journal of Scientific Research and Reviews, 1, 60-68
available at: http://www.wudpeckerresearchjournals.org

7 Thermal image definition. Flir. Retrieved 17 August 2018
available at: https://www.flir.com/discover/how-does-an-ir-camera-work/

APPENDICES

APPENDIX A. SKETCH MINIVUX 1DL

The next sketches show all dimensions of the mount.

A.1. Minivux 1DL assembly

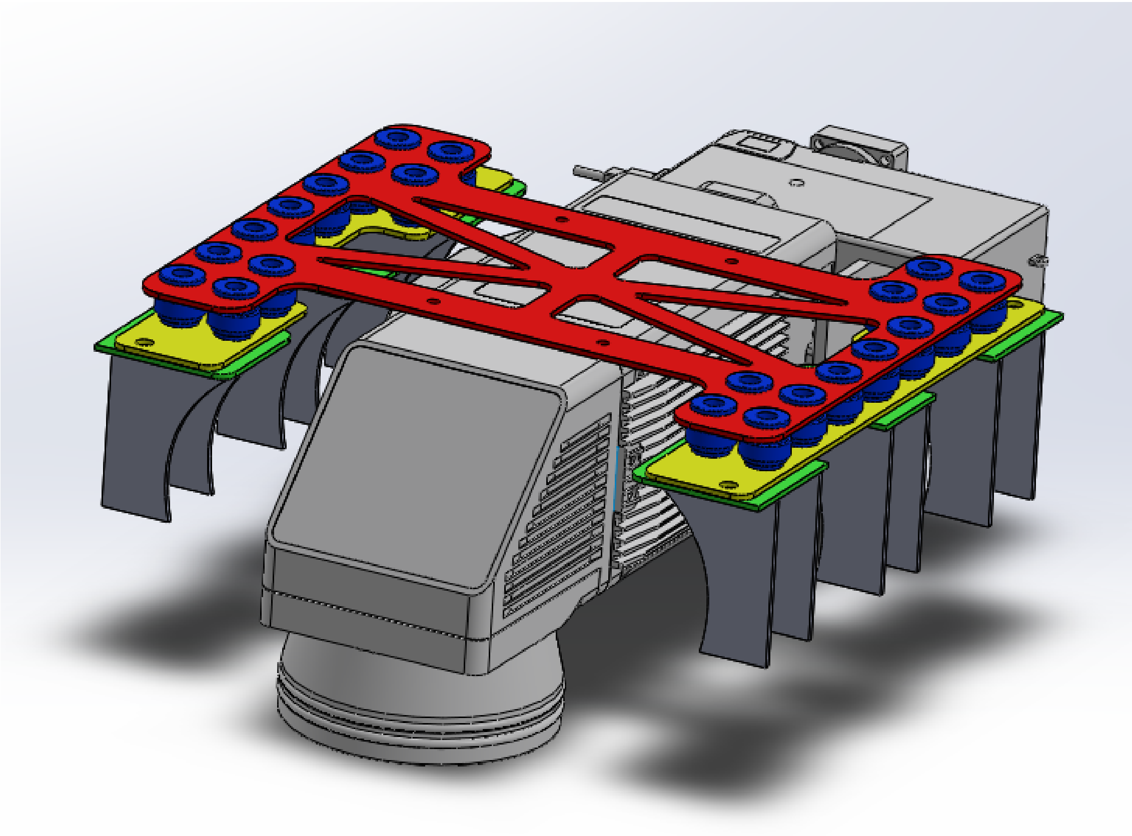


Figure A.1: Sketch Minivux 1DL. Assembly

A.2. Rib

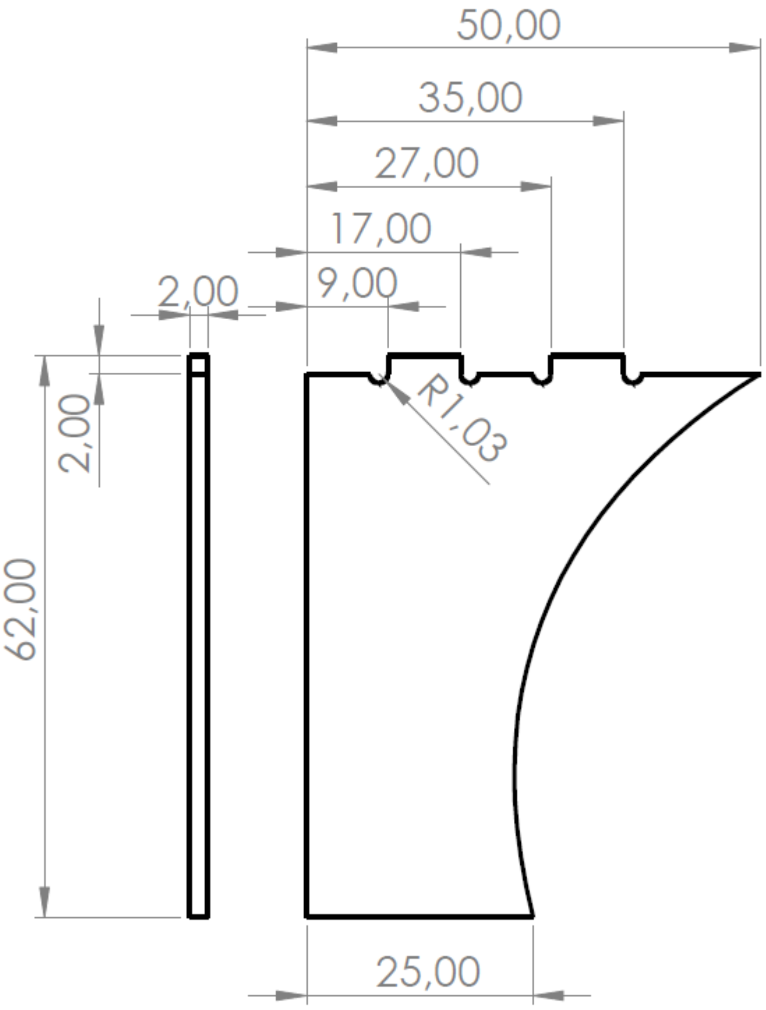


Figure A.2: Sketch Minivux 1DL. Rib

A.3. Rib top mount

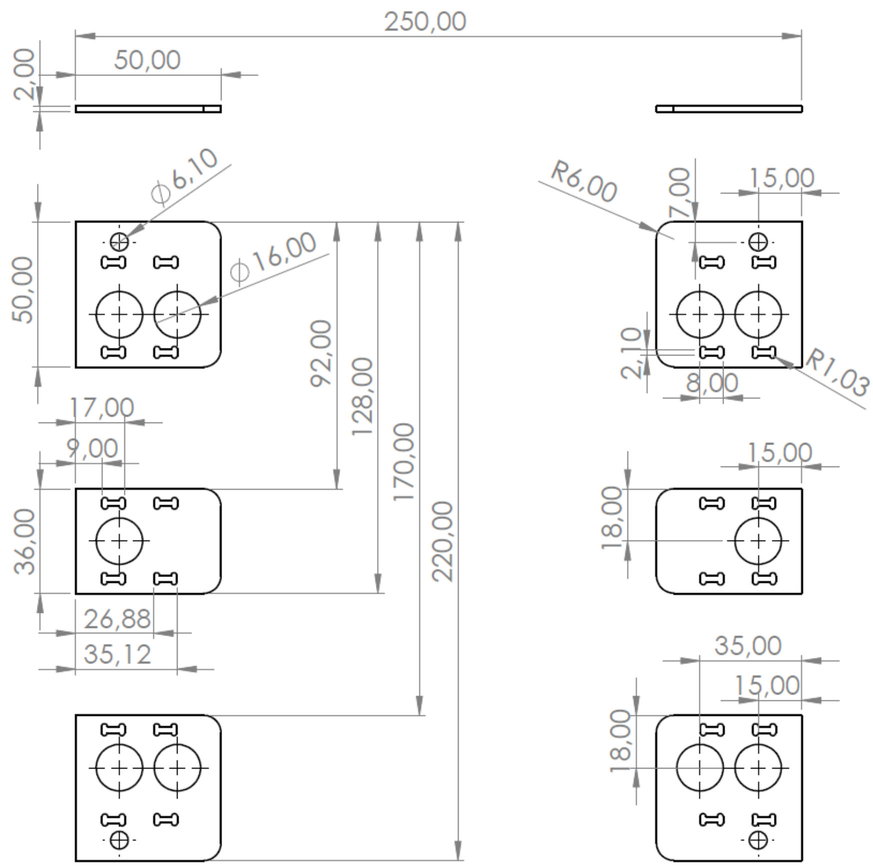


Figure A.3: Sketch Minivux 1DL. Rib top mount

A.4. Bottom mount

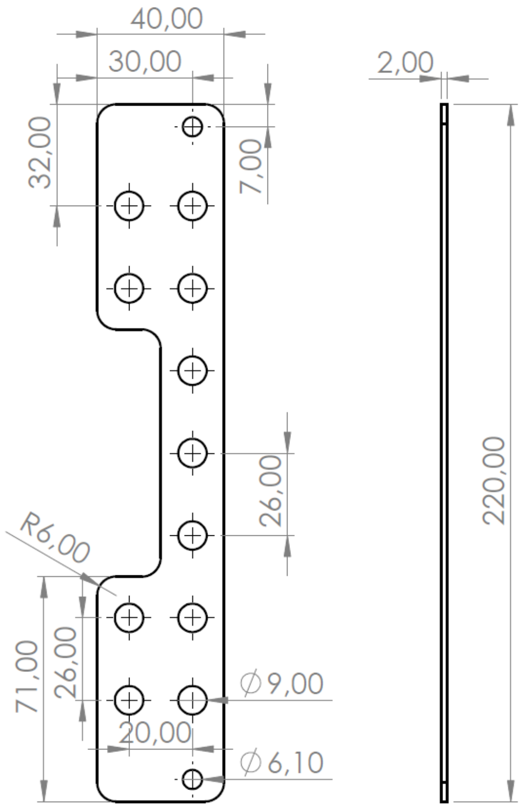


Figure A.4: Sketch Minivux 1DL. Bottom mount

A.5. Top mount

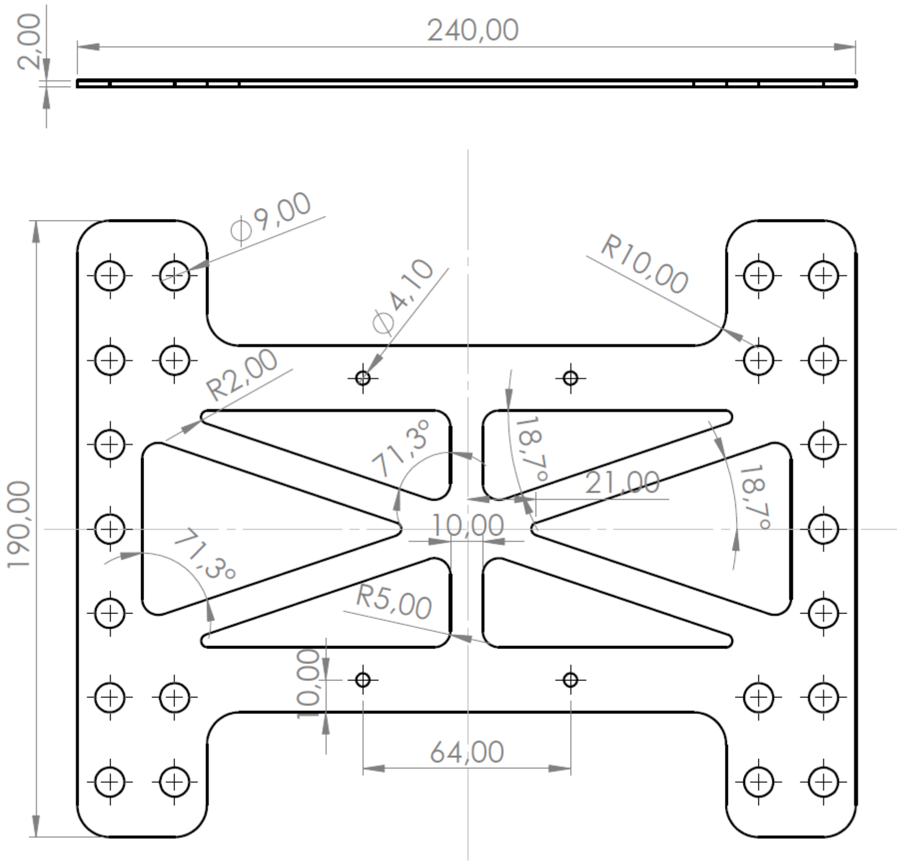


Figure A.5: Sketch Minivux 1DL. Top mount

APPENDIX B. SKETCH CM100

The next sketches show all dimensions of the CM100 mount.

B.1. CM100 assembly

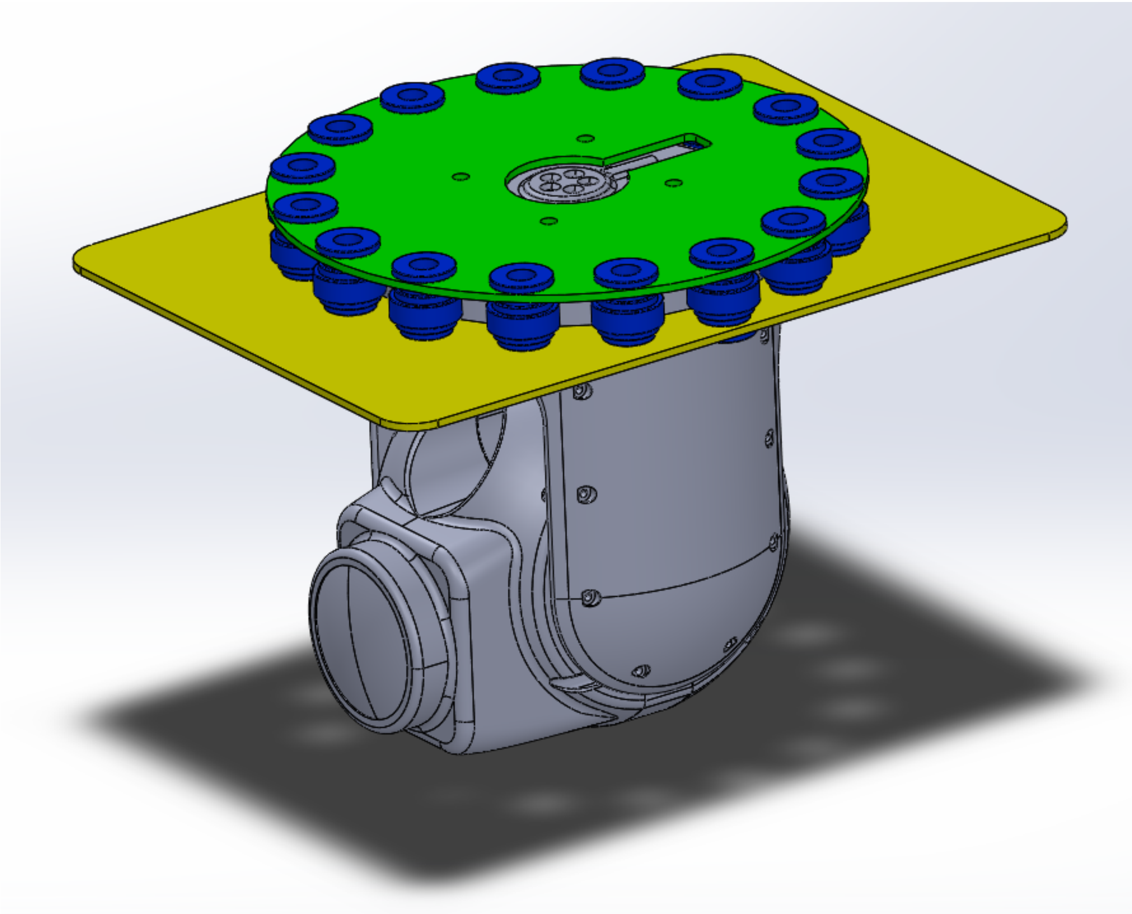


Figure B.1: Sketch CM100. Assembly

B.2. Top part

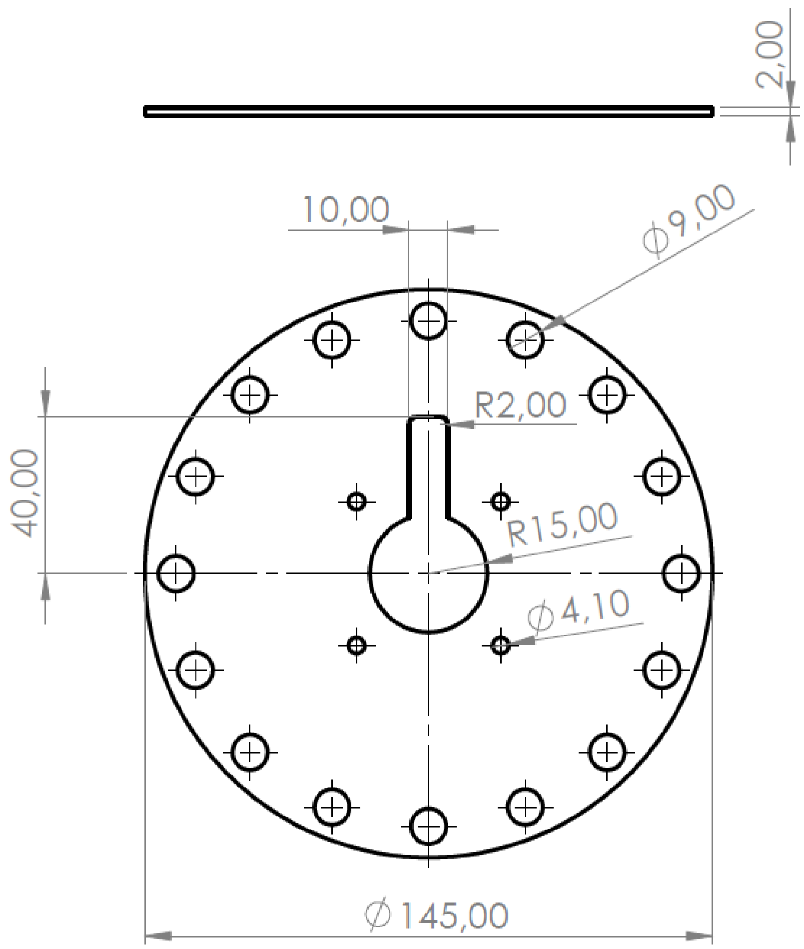


Figure B.2: Sketch CM100. Up part

All dimensions are in mm.

B.3. Bottom part

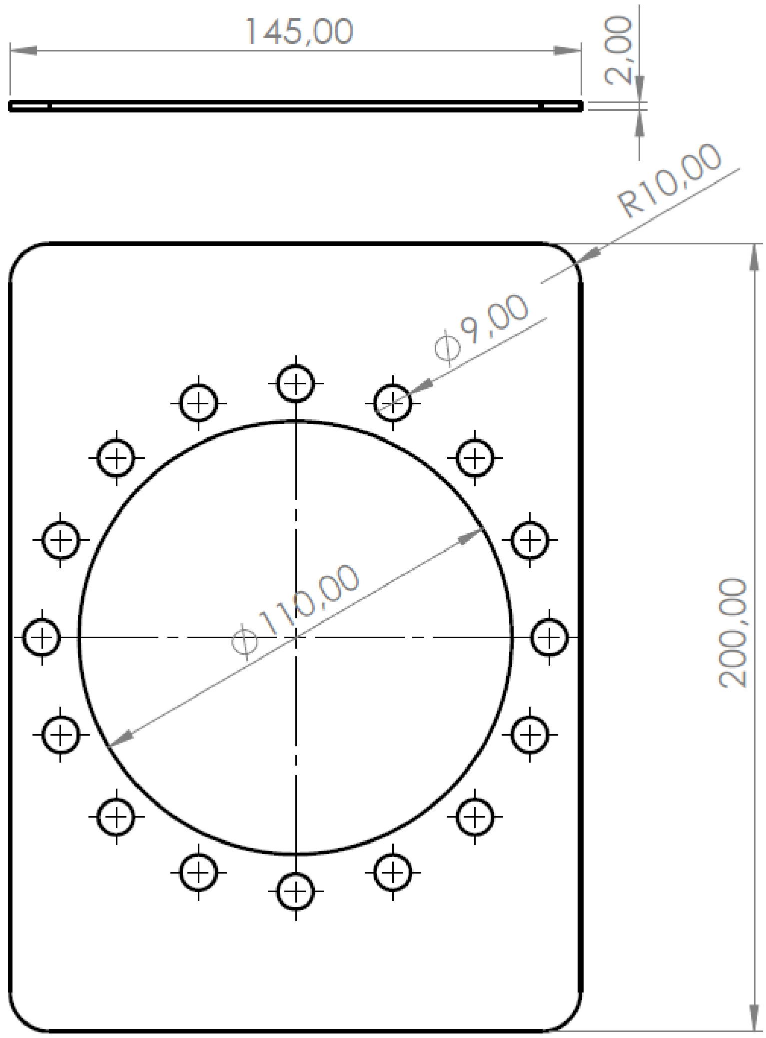


Figure B.3: Sketch CM100. Down part

All dimensions are in mm.
The width and length of the piece may change depending on the fuselage of the airplane.

APPENDIX C. SKETCH YELLOWSCAN SURVEYOR

The next sketches show all dimensions of the CM100 mount.

C.1. Yellowscan Surveyor assembly

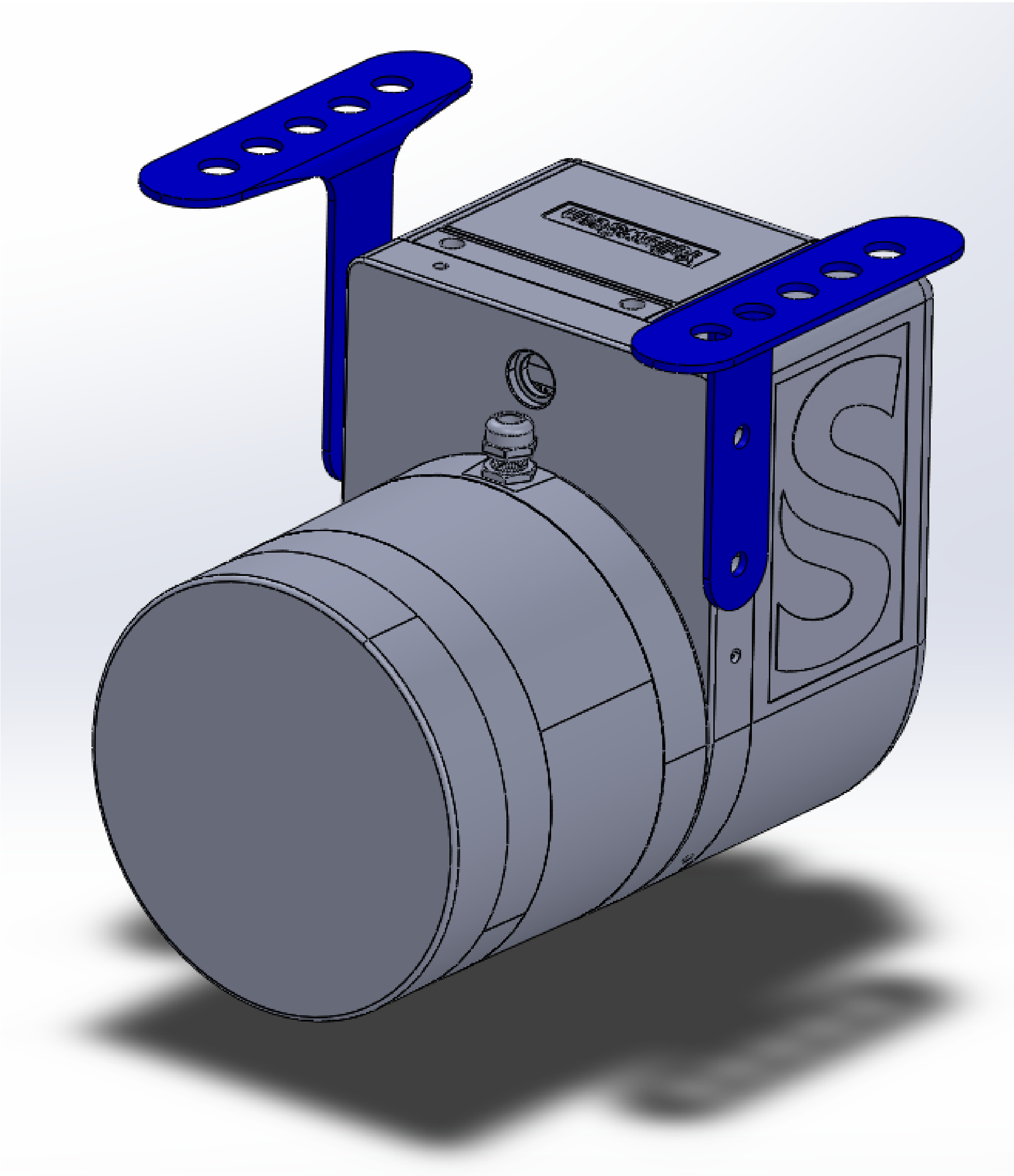


Figure C.1: Yellowscan Surveyor. Assembly

C.2. Mount

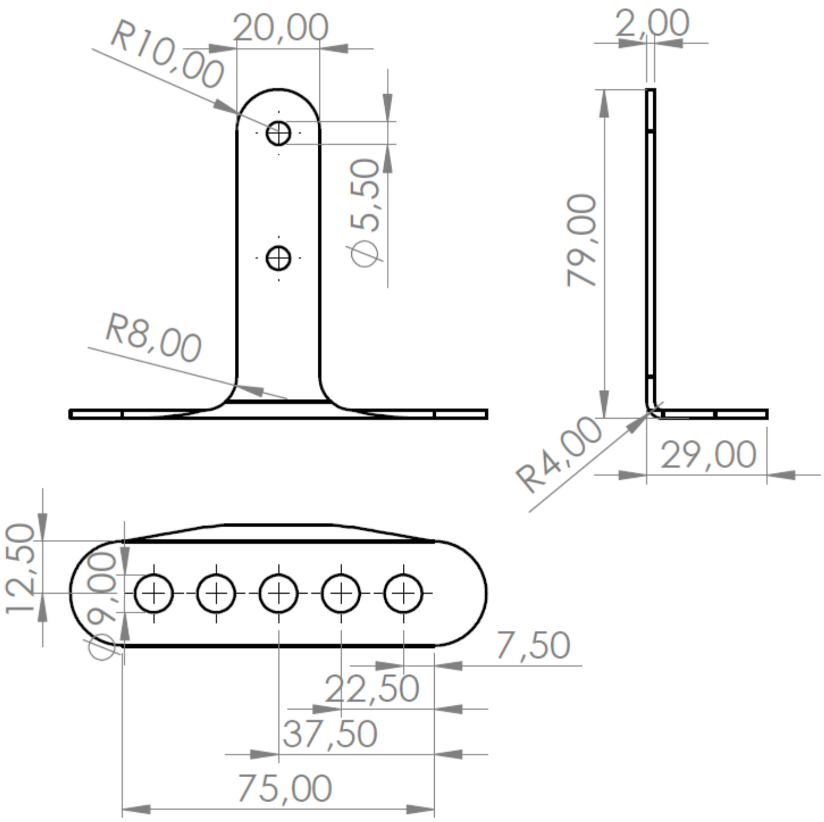


Figure C.2: Sketch yellowscan surveyor. Mount

All dimensions are in mm.

APPENDIX D. DAMPING BALL

All the damping balls used for the mounts of the payloads are for carbon fiber sheets of 2mm of thikness.
In the following figure there are all dimensions of this damping balls.

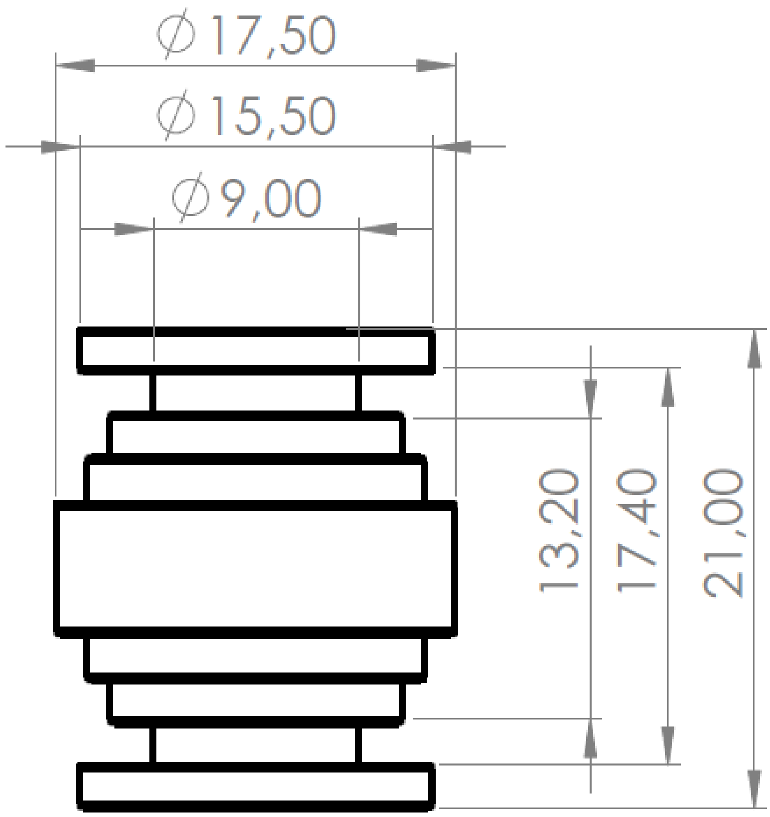


Figure D.1: Sketch. Damping ball